Cracking Engineering Physics through Crossword Puzzles: A Gamified Active Learning Approach to Enhance Engagement and Concept Retention

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Abstract
This study intends to examine how well gamified active-learning resources, more especially, crossword puzzles, improve student engagement, memory and conceptual understanding of physics topics in first year engineering students. This study offers a scalable, interactive teaching approach intended to close the gap between passive listening and active cognitive involvement in technical subjects, even though standard lecture-based engineering approaches frequently result in shorter attention spans and poor memory. The method uses gamification to turn rote memorizing of technical terms and difficult ideas into a fun, competitive and introspective experience that supports certain learning objectives based on the active learning principle. Crossword puzzles were used as tools for review and pre-assessment of about 300 undergraduate B. Tech students from different branches. A mixed-methods strategy was used to collect the data, measuring both quantitative gains and qualitative involvement through the use of pre- and post-quiz scores, mid-semester examination results, and structured student feedback. As per the results obtained, crossword puzzles are a useful addition to engineering education since they greatly increase conceptual clarity and technical language memory. These findings imply that the drawbacks of conventional physics instruction can be effectively addressed by incorporating gamified components.

Keywords: Active Learning, Crossword Puzzles, Engineering Physics, Concept Retention, Student Engagement.

Introduction

Fostering student enthusiasm for the subject matter and the learning process depends heavily on a teacher's professional skill, especially on their capacity to communicate information efficiently and create an engaging and enjoyable learning environment. In a perfect learning environment, students are motivated to observe and investigate the facts of their surroundings by means of significant and enduring educational experiences. They are persuaded to actively interact with their environment, which fosters awareness and effective utilization of instructional materials. One key strategy for skill development is active learning, which involves students actively participating in the educational process. Students become active learners rather than passive recipients of evaluations as they acquire new abilities, values and attitudes. Active learning facilitates students to consider their own attitudes and values in addition to focusing on skill development (McKeachie 2006; Kasilingam et. al. 2014; Harmann 2011; Hake 2002; Dol et. al. 2017). Active learning methods implemented in the form of lectures, simulations, debates, student presentations, games, role-plays, flip charts and handouts are crucial elements. Active learning comprises three interrelated elements. These include educational tools, learning methodologies and fundamentals (Kintu et. al. 2016; Kumar et. al. 2010; Ritzko 2011; Velaora et. al. 2021; Pivec 2007).

First-year engineering curricula include engineering physics as a core science course that serves as the conceptual and mathematical basis for subsequent discipline-specific courses. Most of the time students perceive this subject as abstract, fast-paced, and substantially content-driven, which results in poor learning, anxiety and disengagement. Traditional teaching methods frequently treat students as passive consumers and make it difficult for them to focus and engage in deep conceptual processing for the duration of a session. Research in scientific and higher education regularly demonstrates that teacher-centred approaches are linked to poor long-term retention, restricted conceptual change and inadequate transfer of knowledge to novel challenges. Gamified methods and active learning have become popular tactics for raising student motivation, engagement and comprehension, making it learner centric. According to numerous experimental research in physics and science education, incorporating game-

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like tasks and challenges improves time on task, participation and frequently, academic performance when compared to non-gamified activities. Compared to traditional settings, gamified environments are typically more immersive and interactive, encouraging deeper processing of complicated topics, active engagement and teamwork. Additionally, analytical data shows that gamification improves learning results overall, with its effects being moderated by user type, discipline, and design principles (Croft 2010; Huynh 2012; Falkner 2010; Franklin 2006; Sannathimmappa 2023; Huang 2014; Maheshwari 2021).

In this context, game-like resources such as puzzles and tests provide a practical means of implementing gamified, active learning in classrooms with lots of students or limited resources. In higher education, crossword puzzles in particular have been utilized as formative evaluation tools to strengthen conceptual links, terminology and definitions. Studies from the field of health and food science demonstrated that the use of crossword puzzles tends to increase learner's engagement and perceived comprehension of the course material (Agarwal 2020; Babayemi 2014; Bryant 2016; Venkata 2023; Veena 2025; Mehta 2025). Evidences from medical and pharmacy education show that crossword based exercises can help with the learning and retention of technical terminology and domain-specific knowledge. These results are in line with more extensive research on game-based and puzzle-based learning, which emphasizes the advantages of activities that are closely matched with learning objectives for motivation, attention, cooperation and information retrieval (Shetgar et al. 2018, Weisskirch et.al. 2010; Zamani et. al. 2021; Udeozor et. al. 2021).

Though there are many evidences showing the implementation of gamification and puzzle based learning methods in various domains, engineering physics remains relatively underexplored. Most of the existing work on gamified physics education focuses on digital games or simulations targeting specific topics like mechanics, motion and trajectories and demonstrates increased engagement and more dynamic learning, sometimes with modest but positive impacts on quiz performance. In higher education, there is also concern that some gamified experiences emphasize extrinsic rewards without adequately fostering autonomy, relatedness and meaningful cognitive challenge, which are critical to intrinsic motivation and deep learning. Within this context, we see that crossword puzzles offer a promising, yet underutilized, form of content gamification for engineering physics. These types of learning activity can embed formulas, core concepts, units and relations directly in the puzzle structure that requires students to recall and apply knowledge (Saran et. al. 2015; Njoroge et. al. 2013; Patrick 2018; Naik 2023; Sargar et. al. 2024; Basakova et. al. 2024). There is a lack of published research on carefully crafted, course outcome mapped crossword puzzles for first-year engineering physics, regardless of the fact that crossword-based interventions have been studied in fields like anatomy, pathology, and food science with positive effects on engagement and perceived understanding. Particularly, there is a dearth of quantitative data relating the usage of crossword puzzles to success on common course tests and idea memory, as well as organized research on students' perspectives in this particular setting.

The purpose of this investigation is to design, implement and evaluate crossword puzzles as a structured active-learning strategy for Engineering Physics and to measure their impact on student engagement, learning outcomes and concept retention; assess the value of crossword puzzles as a cutting-edge teaching and learning tool.

The following are the objectives of the study performed:

(i) To evaluate the how effective crossword puzzles are in improving the understanding and retention of fundamental concepts and technical vocabulary in Engineering Physics.
(ii) To assess student feedback and perception about embedding crossword puzzles within the teaching methodology and to determine the impact of crossword-based learning on academic performance in engineering physics topics.
(iii) To explore the role of crossword puzzles in reducing cognitive load and enhancing long-term memory retention.
(iv) To evaluate how crossword puzzles support the revision and reinforcement of complex theories and formulas in Engineering Physics.

The present study addresses the gap by implementing a gamified active learning that incorporates thoughtfully crafted crossword puzzles into a first-year engineering physics course used to crack the concepts of engineering physics. The puzzles are used as in-class activity and are clearly linked to the course objectives and important conceptual clusters. The study uses a mixed method design that incorporates pre and post-tests, internal examination results, mid- term results and structured student feedback to assess the efficacy of crossword puzzles. The work intends to add empirical evidence to the larger literature on gamification and active learning in engineering physics, as well as useful advice for teachers, by concentrating on a low-cost, readily scalable gamified tool.

Methodology

This concept follows the Bloom's Taxonomy framework which categorizes learning into different cognitive levels like knowledge, comprehension, application, analysis, synthesis and evaluation. Crossword puzzle activities primarily focus on to engage the knowledge and comprehension levels that require students to recall technical terminology, definitions and concepts related to the given physics topics. Additionally, the crossword puzzle solving also supports active learning, where students actively participate in constructing knowledge rather than passively receiving information. These types of mere practice, which has been shown to strengthen memory and conceptual reinforcement in educational settings.

This study was conducted at a private engineering institute located in Mumbai, Maharashtra. Sample size consisted of 128 respondents who are engineering undergraduate students (first year) from Computer Engineering, Information Technology, Mechanical Engineering, and Electronics & Telecommunication Engineering. Crossword puzzles were designed and curated by the faculty members to ensure alignment with specific physics topics including Semiconductors, Photonics and Engineering Materials. Questions focused on key concepts, definitions, formulas and technical terminology with different difficulty levels (easy, moderate and difficult). Puzzles were created using online tools (Figure 1) and reviewed manually to ensure academic relevance. The crosswords were created using online websites like https://crosswordlabs.com/ and https://puzzlemaker.discoveryeducation.com/.

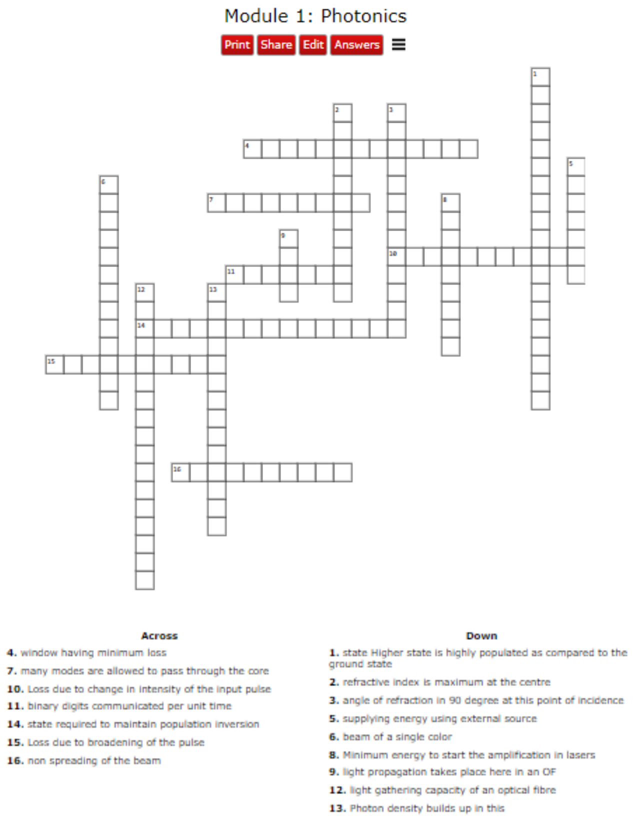

Figure 1. Sample crossword on Photonics

A set of questions with single-word answers was provided to the website, which automatically generated the crossword puzzles. The crossword puzzle was shared with the group of learner's using the Institutes customized LMS Moodle. Students were instructed to work in a team of 2 and solve the puzzle in time duration of 30 minutes. Assessment was conducted using MCQ-based quizzes (pre- and post-activity) as well as internal assessment and mid-semester exam scores. Once they finished, they were instructed to share the PDF version of their completed puzzle on the drive linked shared with them in advance, after which the correct answers were disclosed as is illustrated in Figure 2.

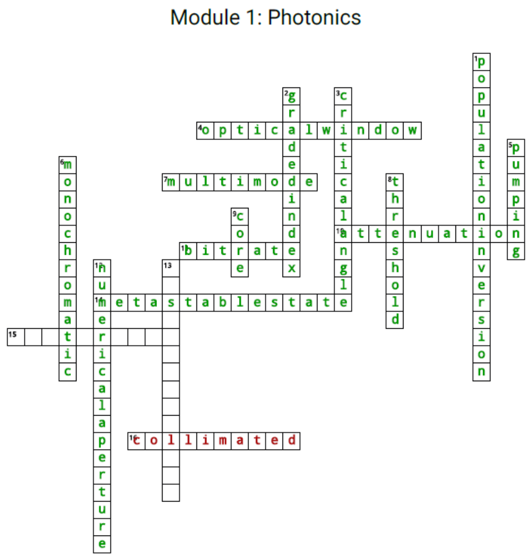

Figure 2. Completed Crossword puzzle attempted by the students

An online student perception survey was conducted using a structured questionnaire administered through Google Forms and based on a 5-point Likert scale. The questionnaire included items designed to capture students' views and experiences regarding the use of crossword puzzles as a learning tool. The collected feedback responses were further analyzed to assess internal consistency.

Results and Discussion

Student's performance analysis

The study was conducted with approximately 300 first-year undergraduate (B. Tech) students enrolled in the Computer Engineering, Information Technology, Mechanical Engineering and Electronics and Telecommunication Engineering branches respectively, at a private engineering institute in Mumbai. Participation in the instructional activity was integrated with regular classroom teaching. Among them, 263 students actively participated in the crossword puzzle activities conducted during the sessions. The statistical analysis was done only for the students who completed both the pre-test and post-test assessments with complete and matched responses. After excluding the incomplete submissions and unmatched responses, 128 students constituted the final matched dataset, which was used for the paired statistical comparison of pre- and post-activity quiz scores. The approach ensured that the analysis was based on paired observations from the same participants, thereby improving the validity of the comparison.

The effectiveness of crossword puzzles as a learning tool was assessed by comparing students' performances for both the modules in the internal assessments (MCQ based quiz) and mid-semester test. A pre-test–post-test design was employed in which an Internal Assessment (IA) was conducted before introducing crossword puzzles and a second Internal Assessment their after implementation to measure impact on student learning outcomes. 128 students actively participated and appeared for both the internal assessments. Students not only thoroughly enjoyed the activity but also completed the crossword independently, without relying on external resources such as books or the internet in the given time.

Student performance in Internal Assessment (IA) and Internal Assessment-2 (IA-2) reveals a clear improvement in overall academic attainment as shown in Figure 3.

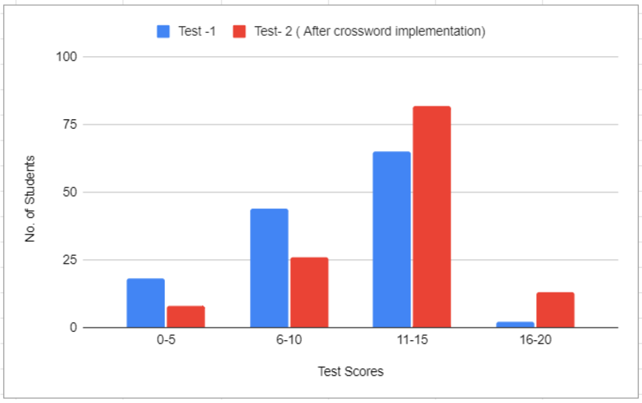

Figure 3. Students' performances in the internal assessments pre and post crossword puzzle activity.

In Category I (0–5 marks) students, number of students dropped markedly from 18 in IA to 8 in IA-2, representing a decline of nearly 59%. This decrease indicates that several students who initially struggled with the subject content were able to improve their performance in the subsequent assessment after crossword practice. A similar kind of pattern was observed in the students of category II (6–10 marks), where the number of students decreased from 44 in IA to 26 in IA-2. The combined decline in the lower performance categories (0–10 marks) clearly indicates that a significant number of students moved into higher score categories in the second assessment. A substantial increase from 65 students in IA to 82 students in IA-2 is seen where the students fall in category III (11–15 marks), indicates that a large portion of students improved their speculative understanding and hence, were able to perform better in the subsequent evaluation. A significant rise in the student from 2 in IA to 13 students in IA-2, reflects a notable rise in high-achieving students in Category IV (16 -20 marks). The decline in Category I & II students combined with the increase in Category III & IV students suggests improved comprehension and retention of course concepts. Such improvement aligns with the principles of Bloom's Taxonomy from a pedagogical viewpoint, where reinforcement of knowledge and comprehension through active learning strategies supports progression toward higher levels of cognitive attainment. Therefore, crossword puzzles can be used as a supplementary tool along with regular lectures for enhancing learning outcomes.

A paired samples ***t***-test was conducted to compare student's performance on the crossword pre-test and post-test to determine the effectiveness of the instructional intervention and the results are displayed in Table 1. The studies performed using paired *t*-test is appropriate because the same group of students (n = 128) participated in both assessments, thus allowing for the evaluation of mean differences within matched observations.

Table 1. Summary of the statistical analysis

Metric	Pre-Test	Post-Test
Mean Score	11.41	14.03
Standard Deviation	4.27	3.12
Sample Size (n)	128	128
t-statistic	5.772	
p-value	< 0.0001	

Using this statistical method, we ascertain whether the average difference between pre- and post-intervention ratings deviates considerably from zero. The mean score shows an increase from M = 11.41 (SD = 4.27) in the pre-test to M = 14.03 (SD = 3.12) in the post-test, indicating an average gain of 2.62 points following the teaching intervention. The reduction in standard deviation (SD) from 4.27 to 3.12 clearly suggests slightly more consistent performance among students after instruction. A statistically significant difference between pre-test and post-test scores was found using the paired samples t-test (t (127) = 5.772, p <.0001). The obtained p-value 5.67×10^{-8} is significantly less than the standard significance level of $\alpha = 0.05$. The null hypothesis states that there is no significant difference between the mean scores from the pre-test and post-test and is rejected since the computed p-value is significantly below the 0.05 cut-off. The findings show that it is unlikely that the observed mean improvement happened by accident. The observed increase in mean scores from 11.41 to 14.03 reflects a meaningful enhancement in students' understanding of the subject content as measured through the crossword assessment. The large *t*-value and highly significant *p*-value suggest that the teaching strategy employed had a positive and measurable impact on student's learning outcomes. Overall, these findings provide empirical support for the effectiveness of the instructional approach in improving student's conceptual understanding, as evidenced by their enhanced performance in the post-intervention crossword assessment. The findings suggest that incorporating crossword puzzles into physics lectures significantly enhances student performance. Students exposed to crossword-based activities not only retained subject-specific terms better but also demonstrated improved conceptual understanding, which translated into higher exam and assessment scores. The higher gain in internal assessments highlights that crossword puzzles improved continuous engagement and recall, while the greater improvement in mid-semester exams indicates better long-term retention and problem-solving skills.

Feedback Analysis

Overall responses from 128 students show that the students welcomed crossword puzzles as a diversion from the usual lectures and felt they added interest and motivation to the teaching and learning process. In response to the level of difficulty of crossword, varied responses were obtained from the students regarding their experience with the activity as reflected in Figure 4.

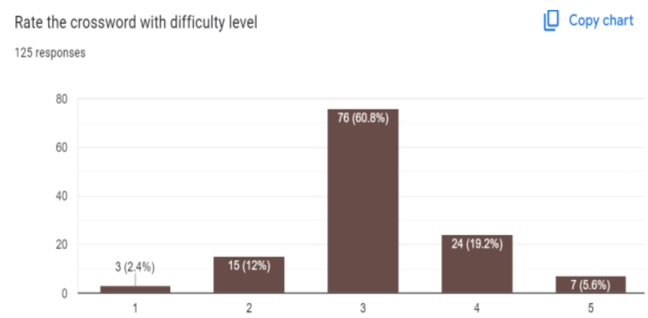

Figure 4. The bar graph showing the difficulty level of the crossword activity received from the students responses

The variation in the answers shows that the students' cognitive ability and the crossword puzzle's difficulty level were suitably matched. Around 60.8 % of the respondents gave the activity a moderate difficulty rating (level 3), indicating that the puzzle activity offered an ideal degree of difficulty thus promoting active participation without placing an undue cognitive burden on participants. Additionally, 24.8% of the students find the puzzles difficult hence, gave it a higher difficulty ratings (4–5) which suggests that some students found the activity to promote deeper cognitive thinking. A relatively smaller proportion of responses lie in the lower difficulty categories (14.4% for levels 1–2) suggests that the activity was not perceived as trivial.

The overall findings demonstrate that crossword puzzles functions as an effective active learning strategy that promotes engagement and conceptual reinforcement among first-year engineering students.

Reponses from the student perception survey, capturing learners' experiences and opinions of the crossword activity, were collected and analysed. As per obtained responses majority of the students had an excellent experience. Table 2 depicts the findings of survey on a 5-grade evaluation scale to assess students' opinions and perception about cross word puzzle activity in classroom (5=strongly agree, 4= agree, 3=neutral, 2=disagree, and 1=strongly disagree).

Table 2. Feedback questionnaire of crossword puzzle activity

Feedback Questions	5 (%)	4 (%)	3 (%)	2 (%)	1 (%)
Did you find solving the crossword puzzle enjoyable?	59.26	37.78	2.96	0	0
Do you believe that thinking is necessary for problem-solving and that this has improved your ability to think?	52.32	43.71	3.97	0	0
Do you think concentration is necessary to solve the puzzle?	53.80	43.67	0.63	1.90	0
Did you remember the subjects as you worked through the puzzle?	53.50	44.59	1.27	0.64	0
Do you think a student can also be evaluated using a crossword puzzle?	47.47	46.84	3.16	0.63	1.90
Solving crossword puzzles in the classroom is a good appraisal of lecture content.	63.57	32.86	1.43	2.14	0

More than 90% of students selected 4 or 5 for most questions, indicating strong agreement. The highest "Strongly Agree" response (63.57%) is for crossword puzzles being a good appraisal of lecture content. Negative responses (2 or 1) are very minimal (<3%), showing overall positive acceptance. Students agreed that crossword puzzles were interesting. They enjoyed it and would surely like to have more such activities in class after a topic is taught which will help students to prepare for the concepts. Crossword puzzles encourage conversation in small groups and foster critical thinking. Hence, it can be inferred that the appropriate implementation of crossword activities has the potential to positively impact student's learning outcomes and significantly enhance their engagement within the classroom environment.

Figure 5 illustrates students' ability to recall theoretical topics while solving the crossword. According to the figure, majority of students (72.2%) said "Yes," indicating that the crossword exercise successfully enhanced their capacity to remember theoretical ideas discussed in the course. 27.8% of respondents chose "moderate," suggesting that although the exercise improved recalling, learners' perceptions of the effect differed based on their level of participation or prior knowledge. Interestingly, no replies expressed a negative opinion, suggesting that students generally thought the activity was beneficial for strengthening conceptual memory.

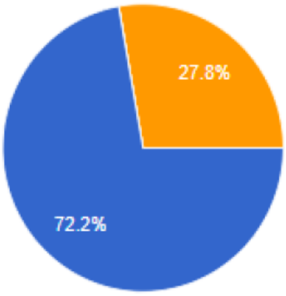

Figure 5. Ability to recall theory topics after attempting crossword puzzle activity

The students' feedback analysis clearly suggests that crossword puzzles are interactive and motivate the students to recall definitions, terms and conceptual connections related to the subject. Learner's feedback response also included the following remarks (i) Crossword puzzles helps creating a relaxing atmosphere as compared to the tedious lectures (ii) increases the interaction, enjoyment of simultaneously learning the subject and (iii) guessing the right spellings helped them solidify their knowledge and thus, they all agreed that more such crossword puzzles ought to be available for all the topics of the physics module in the future.

Moderate claims regarding long-term retention are observed. Long term retention can be correlated with the scores of mid semester examination, as the modules used for crossword activity in class and the modules for mid-semester examination was the same. Figure 6 represents the distribution of mid-semester examination (MSE) scores demonstrating overall student performance. The scores in the mid-semester examination indicate 67.4% of students scored within the 11–15 marks range, 30.2 % scored in the 16–20 marks range, only a small fraction of students (1.6%) scored within the 6–10 marks range, and an almost negligible proportion scored below this range, indicating an overall positive learning outcome across the cohort. This distribution suggests approximately 97.6% of students (11-20 mark range) were able to retain and apply key physics concepts during formal assessment. The improvement in mid-semester exam scores to some extent suggests that the crossword activity may have supported students' retention and recall of theoretical physics concepts, which likely contributed to improved student performance.

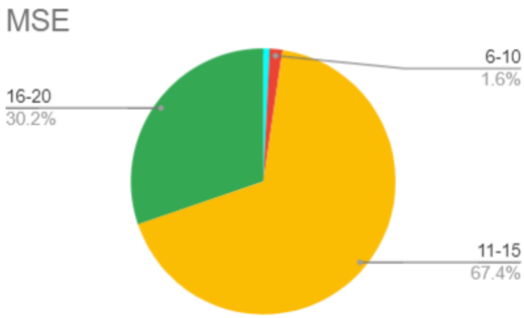

Figure 6. Distribution of Mid-Semester Examination (MSE) scores demonstrating overall student performance following the crossword-based learning activities.

Although improved performance in the mid-semester examination suggests effective reinforcement of course concepts, the study did not include delayed post-tests or standardized cognitive load measurements; therefore, claims regarding long-term retention and cognitive load reduction should be interpreted with caution.

Targeted learning outcomes are positively correlated with gamified instructional methodologies, according to the activity–outcome mapping described in Table 3.

Table 3. Activity–Outcome Mapping of Gamified Learning Intervention in Engineering Physics

Activity	Outcome Achieved
Crossword solving	Improved recall of physics terminology
Peer discussion	Enhanced collaborative learning
Timed puzzles	Increased focus and engagement
Feedback survey	Insight into learner perception

Solving crossword puzzles of engineering physics helped students to recall the terminology. In line with social constructivist ideas, peer conversations encouraged collaborative knowledge building. Timed puzzle exercises improved classroom engagement and student focus. Additionally, the feedback survey showed that students had a favourable opinion of these interactive techniques, pointing to both cognitive and affective advantages. Integrating multiple gamified strategies provides a holistic approach to enhancing both understanding and motivation in an Engineering Physics course.

Conclusions

Crossword puzzles prove to be a creative way to teach and learn. They add concept retention as well as active student participation in class. The study indicates that the crossword puzzles can be an effective supplementary tool in engineering education, as they show to enhance students' speculative and conceptual understanding as well as retention of technical vocabulary. The outcome is supported by the statistical analysis, showing a large t-value and a high significant p-value. When crossword puzzles are used as a teaching strategy, they can have a positive and measurable impact on students' learning outcomes. These studies suggest that the inclusion of gamified activities like crossword puzzles can make learning physics more engaging and interactive. Hence, integrating crossword puzzles with traditional teaching approaches may help address some limitations of conventional physics instruction and enhance the overall learning experience.

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Conflict of interest

The authors declare no conflict of interest.

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